

A Summary of Previous Grand Challenge Proposals for Cognitive Systems

Samuel Bayer
Laurie Damianos
Lynette Hirschman
Gary Strong

The MITRE Corporation

Prepared for DARPA IPTO, September 2004

Version 1.4

Report Documentation Page

Form Approved
OMB No. 0704-0188

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

| | | | | |
|--|----------------|--|--------------------------------------|---------------------------------|
| 1. REPORT DATE SEP 2004 | 2. REPORT TYPE | 3. DATES COVERED 00-09-2004 to 00-09-2004 | | |
| 4. TITLE AND SUBTITLE A Summary of Previous Grand Challenge Proposals for Cognitive Systems | | 5a. CONTRACT NUMBER | | |
| | | 5b. GRANT NUMBER | | |
| | | 5c. PROGRAM ELEMENT NUMBER | | |
| 6. AUTHOR(S) | | 5d. PROJECT NUMBER | | |
| | | 5e. TASK NUMBER | | |
| | | 5f. WORK UNIT NUMBER | | |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) MITRE Corporation, 202 Burlington Road, Bedford, MA, 01730-1420 | | 8. PERFORMING ORGANIZATION REPORT NUMBER | | |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) | | 10. SPONSOR/MONITOR'S ACRONYM(S) | | |
| | | 11. SPONSOR/MONITOR'S REPORT NUMBER(S) | | |
| 12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited | | | | |
| 13. SUPPLEMENTARY NOTES | | | | |
| 14. ABSTRACT | | | | |
| 15. SUBJECT TERMS | | | | |
| 16. SECURITY CLASSIFICATION OF: a. REPORT unclassified | | 17. LIMITATION OF ABSTRACT b. ABSTRACT unclassified | 18. NUMBER OF PAGES 10 | 19a. NAME OF RESPONSIBLE PERSON |
| c. THIS PAGE unclassified | | | | |

1 Overview

The notion of a Grand Challenge (GC) in computational cognition is not new. It has been addressed both specifically and in the context of Grand Challenges in computing as a whole. One well-known example, DARPA's Autonomous Vehicle Grand Challenge (AVGC), has captured the imagination of the media and the public. The AVGC is much more than a compelling research goal or a way to make DARPA's work relevant to the average layperson; it is a measurable test which can tell us where to focus our work and how much we have accomplished. The AVGC has “raised the bar” for what it means for a Grand Challenge to set the agenda for a field of research.

There have been previous efforts to develop Grand Challenges for computer science, but none of these efforts has addressed directly the needs of DARPA IPTO, in particular, demonstrations of cognitive capabilities with a dimension in learning.

To gain insight into why no proposal has yet to become an IPTO Grand Challenge, we performed a historical review and analysis of several sources of GCs in cognitive systems and artificial intelligence (Appendix B). This document summarizes and characterizes these previous Grand Challenge explorations and evaluates categories of proposals against the DARPA IPTO criteria for selecting a GC.

2 Criteria for Selecting an IPTO Grand Challenge

We compiled relevant criteria for selecting a GC from the sources listed in Appendix B, with respect to IPTO-specific requirements. IPTO further refined the compilation, resulting in the following six criteria, with specific components, for selecting an IPTO Grand Challenge.

1. Clear and compelling demonstration of cognition.
 - a. The test should be a proxy for a range of problems requiring cognitive capabilities.
 - b. The test should not be “game-able” or solvable by “cheap tricks”
 - c. It should not be solvable by brute force computation, alone, and it should not lend itself to idiot savant solutions.
 - d. Require integration of multiple cognitive capabilities.
 - i. It is desirable that the portfolio of tests include sensing and acting (i.e., situated cognition)
2. Clear and simple measurement.
 - a. The test should have a clear and simple method for measuring success.
 - b. The test should specify what must be done, not how to do it.
 - c. It is desirable to have a graduated sequence of increasingly more difficult problems.
 - d. It is desirable to have tests that are automatically score-able.
 - e. It is desirable that the tests be easy to create and run and that test results be reproducible.
3. Decomposable and diagnostic.
 - a. The test should be decomposable into sub-tests or sub-measurements for different aspects of cognition.
 - b. The test should be diagnostic (failure to pass the test should point the way to future improvements).
 - c. It would be desirable to have partial, intermediate results (scores are not just “Pass/Fail.”)
4. Ambitious and visionary, but not unrealistic.
 - a. It should not be a toy problem.
 - b. It should represent technical/scientific goals achievable within a 10-20 year window.
 - c. It should not be something that a computer can already do.
 - d. Desirable to have military relevance (eventual)
5. Compelling to the general public.
 - a. It should be simple to explain and convey to the general public.
6. Motivating for the researchers.
 - a. It should generate enthusiasm in the research community.
 - b. It is desirable to have a low cost of entry so that work on the problem can begin right away.
 - c. It is desirable to enable continuous testing, perhaps over the web.

3 A Review of Previous Grand Challenges

For historical purposes, we collected, compiled, and reviewed many proposed Grand Challenges (see Appendix A for a brief listing). In general, we found that proposals focusing on problems without specifying details of the solution do not provide enough direction for a GC. For example, “Use computational cognition to solve the problem of unemployment.” Alternately, proposals focusing on specific cognitive capabilities, without specifying how those capabilities will be used, (e.g., “Learn to Speak as Well as a Human”) are difficult to measure.

We chose to focus our analysis on task-based GCs as the most appropriate for IPTO. Task-based GCs are more likely to be organized around a goal whose achievement can be measured, decomposable and diagnostic, and whose usefulness and relevance is clear. An example of one such task-based GCs is “Lead an Orienteering Team to Victory.”

For purposes of discussion, we have clustered all GC proposals into categories. (Note that some proposals may be grouped incorrectly due to lack of detail.) We then evaluated each proposal against the criteria for selecting an IPTO GC and summarized these evaluations, by category, in Table 1.

Most of these criteria do not lend themselves in all cases to a yes or no answer. In our evaluation, we used a ‘+’ sign to indicate that a category rated highly against a criterion for all or most GCs in that category and a ‘-’ where the category rated poorly against a criterion. Where different GCs within a single category rated differently, or where ratings were ambiguous, we used no marking at all. Unknown values are indicated by a ‘?’.

The results of our evaluation indicate that no single GC category is strong in all areas of the criteria that are important to IPTO. While it is difficult to judge whether a GC will be motivating to researchers (6a) or simple to explain (5a), it seems that GCs fail more often than not to be clear and simple to measure (2) or decomposable and diagnostic (3).

| Criteria | Grand Challenge Categories | | | | | | | | | | | | | | |
|---|----------------------------|----------------------|----------------------------------|-------------|-----------------------------------|--------------------|--------------------|-----------------------|---------------------|-----------------------|---------------------|--------------------|------------|---------------------|---------------------|
| | Take a Test | Analyze and Persuade | Learn Then Do / Learn Then Teach | Play a Game | Location-Aware Logistical Support | Personal Assistant | Scientific Support | Communication Support | Physical Activities | Collaboration Support | Creative Activities | Question Answering | Prediction | Human Impersonation | Deception Detection |
| 1. Clear & compelling demonstration of cognition | | | | | | | | | | | | | | | |
| a. Proxy for problems requiring cognitive capabilities | + | + | + | + | + | + | | + | + | + | + | + | | + | + |
| b. Not “game-able” or solvable by “cheap tricks” | + | + | + | + | + | + | | + | + | + | + | + | | + | + |
| c. Not be solvable by brute force or idiot savant solutions | + | + | + | + | + | + | | + | + | + | + | + | | + | + |
| d. Multiple cognitive capabilities | + | + | + | + | + | + | | + | + | + | + | + | | + | + |
| 2. Clear & simple measurement | | | | | | | | | | | | | | | |
| a. Clear & simple measure of success | + | - | | + | - | - | - | | - | - | | + | | | |
| b. Specify what, not how | + | + | + | + | + | + | + | + | + | + | + | + | + | + | |
| c. Sequence of increasingly difficult problems | + | | + | | + | | | + | + | + | | + | - | - | |
| d. Automatically scoreable | + | - | | | - | - | - | - | | - | - | | + | - | |
| e. Tests easy to run & reproducible results | + | | + | | - | + | | | + | | | | - | - | |
| 3. Decomposable & diagnostic | | | | | | | | | | | | | | | |
| a. Decomposable into sub-tests or sub-measurements | | - | | - | | | | + | | | | - | - | | |
| b. Diagnostic | | | | + | | - | - | | + | | - | | - | - | |
| c. Intermediate results | + | | | + | + | | | + | + | + | + | + | - | - | |

Table 1 Grand Challenge Proposal Categories Rated Against the IPTO Criteria (continued on next page...)

(continued)

| Criteria | Grand Challenge Categories | | | | | | | | | | | | | | |
|---|----------------------------|----------------------|----------------------------------|-------------|-----------------------------------|--------------------|--------------------|-----------------------|---------------------|-----------------------|---------------------|--------------------|------------|---------------------|---------------------|
| | Take a Test | Analyze and Persuade | Learn Then Do / Learn Then Teach | Play a Game | Location-Aware Logistical Support | Personal Assistant | Scientific Support | Communication Support | Physical Activities | Collaboration Support | Creative Activities | Question Answering | Prediction | Human Impersonation | Deception Detection |
| 4. Ambitious & visionary, not unrealistic | | | | | | | | | | | | | | | |
| a. Not toy problem | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + |
| b. Goals within 10-20 year window | + | + | + | + | + | + | + | + | + | + | + | + | - | - | + |
| c. Not do-able now | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + |
| d. Military relevance | | | + | | + | + | | + | + | + | | + | | + | + |
| 5. Compelling to public | | | | | | | | | | | | | | | |
| a. Simple to explain | ? | ? | ? | ? | ? | ? | ? | ? | ? | ? | ? | ? | ? | ? | ? |
| 6. Motivating for researchers | | | | | | | | | | | | | | | |
| a. Generate enthusiasm | ? | ? | ? | ? | ? | ? | ? | ? | ? | ? | ? | ? | ? | ? | ? |
| b. Low cost of entry | + | + | + | + | + | + | + | + | | + | + | + | + | + | + |
| c. Continuous testing | | - | - | + | - | + | | | | - | | - | + | | - |

Table 1 Grand Challenge Proposal Categories Rated Against the IPTO Criteria. + means a GC category ranks highly with respect to a specific criterion, - means a category fails to meet the criterion, ? means unknown, and blank values indicate an ambiguous rating or both positive and negative ratings within the same category.

A. Appendix: Categorized Grand Challenge Proposals

This table represents one of many possible clusterings of Grand Challenge proposals. Note that some proposals may be incorrectly categorized due to lack of detail.

| Grand Challenge Categories | Grand Challenge Proposals | Author/Submitter |
|-----------------------------------|---|-------------------|
| Take a Test | The Language Learner | MITRE |
| | Reading Comprehension | MITRE |
| | The Generic Test Taker | MITRE |
| | Read a Chapter in a College Freshman Text and Answer the Questions at the End of the Chapter | Raj Reddy |
| | Build a Large Knowledge Base by Reading Text, Reducing Knowledge Engineering Effort by One Order of Magnitude | Ed Feigenbaum |
| | Cognitive Decathlon or The Virtual 3 rd Grader: California STAR Challenge | Dave Gunning |
| Analyze and Persuade | The Incident Investigator | MITRE |
| | The Automated Attorney | MITRE |
| | The Digital Debater | MITRE |
| | Handy Andy | Paul Cohen |
| | Cognitive Decathlon or The Virtual 3 rd Grader: Convincing Letter Challenge | Dave Gunning |
| Learn Then Do / Learn Then Teach | The Device Programmer | MITRE |
| | The Master Chef | MITRE |
| | The Tutor and Student | MITRE |
| | Cognitive Decathlon or The Virtual 3 rd Grader: Learning Procedures Challenge | Dave Gunning |
| | Learn to Read, Read to Learn | Lynette Hirschman |
| Play a Game | The Multi-Player Strategy Game Challenger | MITRE |
| | Chess Machine | Raj Reddy |
| | Learn to Do Crossword Puzzles | Barbara Yoon |
| Location-Aware Logistical Support | The Digital Dispatcher | MITRE |
| | The Geo Finder | MITRE |
| | Ubiquitous Safety.Net | CRA |
| | Disaster Management | Paul Rosenbloom |
| | Learn to Use Maps | Barbara Yoon |

| | | |
|------------------------------|---|----------------|
| Personal Assistant | Intelligent Personal Digital Assistant | Bob Balzer |
| | Context-Aware Information Assistant | Dan Siewiorek |
| | Memories for Life | UKCRC |
| | Personal Help Device | Austin Tate |
| | Lifelong Digital Companion | UKCRC |
| | Mnemonet | Nigel Shadbolt |
| | Sensory Augmentation System | Gill Whitney |
| | Computational Companion for the Old | Yorick Wilks |
| | Personal Memex | Jim Gray |
| | Provide a Teacher for Every Learner | |
| | Reading Tutor | Thomas Kalil |
| | Employment Support for Disabilities | Thomas Kalil |
| Scientific Support | Mathematical Discovery | Raj Reddy |
| | Mathematical Assistant | Toby Walsh |
| | Automatic Programmer | Jim Gray |
| | Distilling from the WWW a Huge Knowledge Base, Reducing the Cost of Knowledge Engineering by Many Orders of Magnitude | Ed Feigenbaum |
| | Medical Safety | Thomas Kalil |
| Communication Support | The Translating Telephone | Raj Reddy |
| | Web Understanding Aid | Ehud Reiter |
| | Learning to Interpret Satellite Images | Barbara Yoon |
| | Learn a New Language | Barbara Yoon |
| | Cognitive Decathlon or The Virtual 3 rd Grader: Change of Representation Challenge, Book Report Challenge | Dave Gunning |
| | Speech to Text (Hear as Well as Native Speaker) | Jim Gray |
| | Text to Speech (Speak as Well as Native Speaker) | Jim Gray |
| | See as Well as a Person | Jim Gray |
| Physical Activities | Accident-Avoiding Car | Raj Reddy |
| | On-Road Driving System | NIST |
| | Robot Soccer | Manuela Veloso |
| | Learn to Play Soccer | Barbara Yoon |
| | Learn to Drive | Barbara Yoon |

| | | |
|------------------------------|---|--|
| Collaboration Support | “Smart” Meeting Room Data Collection | NIST |
| | Build a Team of Your Own | |
| Creative Activities | Interactive Electronic Musician | David De Roure |
| | Cognitive Decathlon or The Virtual 3 rd Grader: Creative Writing Challenge | Dave Gunning |
| Question Answering | Deep Thought | Michael Fisher |
| | Google for Images | Andrew Fitzgibbon, Andrew Zisserman |
| | World Memex | Jim Gray |
| Prediction | The Market Predictor | MITRE |
| Human Impersonation | The Turing Test Game Show Player | MITRE |
| | Human-Level AI | Raj Reddy |
| | Model Humans | Paul Rosenbloom |
| | The Feigenbaum Test | Feigenbaum |
| | The Turing Test | Alan Turing |
| | Robot Baby | Paul Cohen |
| Deception Detection | The Deception Detector | MITRE |

Table 2 Previous Grand Challenge Proposals, Categorized

B. Appendix: Sources Consulted for this Review

| Author | Description | Notes |
|------------|---|--|
| UKCRC | submissions to and results from the Grand Challenge development process sponsored by the UK Computing Research Committee (UKCRC), http://www.nesc.ac.uk/esi/events/Grand_Challenge_s/ | 100 submissions, approximately, of which approximately 25 were possibly relevant; 7 GCs proposed, of which one was possibly relevant |
| NIST | a document from Elena Messina at NIST, "Evaluating Cognitive Systems" | list of desiderata for a cognitive challenge problem and for its supporting infrastructure; exemplified through two examples, an on-road driving system and "smart" meeting room data collection |
| Yoon | five slides from Barbara Yoon (DARPA IPTO) on learning challenges | focuses on learning |
| CRA | submissions to and results from on a Grand Challenge development conference sponsored by the Computing Research Association (CRA); report @ http://www.cra.org/reports/gc.systems.pdf | 70 submissions approximately, of which approximately 8 were possibly relevant; 5 GCs, of which 3 are possibly relevant |
| Senator | a briefing by Ted Senator (DARPA IPTO) at the Real World Learning Kickoff Workshop, 4/12-13/04 | briefing on workshop organization, with one slide (16) on challenge problem criteria |
| Cohen | slides from Paul Cohen's AAAI talk "If not Turing's test, then what?" | what's right and wrong with the Turing test, and what a good test would look like |
| MITRE | criteria from MITRE's internal Grand Challenge development exercise for DARPA IPTO; document entitled "'The Grand Challenge' Challenge", October 2003 | presents 15 proposed Grand Challenges, broken down by task, technology, and evaluation requirement |
| Brachman | Ron Brachman, "Systems that Know What They're Doing", IEEE Intelligent Systems, November/December 2002 | |
| Gray | Jim Gray, Microsoft MS-TR-99-50, text of -998 ACM Turing Award lecture "What Next? A Dozen Information-Technology Research Goals", http://research.microsoft.com/scripts/pubs/view.asp?TR_ID=MSR-TR-99-50 | presents ~10 GCs, of which 6 are possibly relevant |
| Feigenbaum | "Some Challenges and Grand Challenges for Computational Intelligence", Edward Feigenbaum, JACM 50.1 (1/2003) | rethinking the Turing Test |
| Gentner | Gentner, D. (2003). Why we're so smart. In Language in mind: Advances in the study of language and thought (MIT Press). http://www.psych.nwu.edu/psych/people/faculty/gentner/newpdfpapers/GentnerWW03.pdf | essential properties of human cognition |

Table 3 Sources Referenced in Analysis